Review for

Simulations of water transport over the Iceland–Scotland Ridge improved by local grid refinement around the Faroe Islands

submitted to: Ocean Science
by: Andrea M. U. Gierisch, Bogi Hansen, Karin Margretha. H. Larsen, and Steffen M. Olsen

---

The manuscript demonstrates that the representation of inflow of Atlantic Water into the Nordic Seas and outflow of Overflow Water, mainly through Faroe-Bank Channel, can be greatly improved by implementing a high-resolution regional nest into a simulation with a coarser grid. The simulated transports show good agreement with observations, both in terms of variability, overall strength, and to a degree also in seasonality. As such, the manuscript clearly demonstrates the impact of model resolution on the simulated transports. This indicates not only that small-scale variability is important to consider, but also that it is possible to obtain realistic overflows even with a z-level grid by increasing the horizontal resolution sufficiently.

Overall statement:
I think that the manuscript is in a good shape, but that the accessibility and reproducibility can be greatly improved by avoiding repetition. This could easily be achieved by merging parts of the discussion into both method and results sections and by explicitly stating all definitions in the method section already, instead of weaving them several times into the results section. The aim of the paper should be stated more clearly. The figures are clear and support what is written in the text. The methods are overall clear, although I think that some details regarding the observational data used for comparison are missing. The tracer part of the study is very exciting, but I am not entirely convinced yet that the method implemented is representing the entire overflows. I am also missing a clear motivation for the purpose of the tracer study, as the aim of the study seems to be to show the model improvement through the implementation of the nested domain. So, in summary, I think that the study is relevant and valuable, but needs some fine tuning in the structure of the manuscript.

In the following, I will highlight "*quotes from the manuscript*" in gray, and "*suggestions*" in dark blue.

General Comments

- In the introduction, I would enjoy a clear statement about the purpose of this paper that you take up again in the discussion. In line 54-55 you ask whether improvements in model performance over a large area can be achieved by implementing a localized high-resolution nest. You do not clearly state in which regard you hope to improve the model. After reading the paper, it becomes clear that you want to improve representation of the overflows, and maybe also import of Atlantic Water into the Nordic Seas. But then you exclude the branch that carries Atlantic Water northwards west of Iceland - so in terms of Atlantic Water, I am not sure what question you are trying to answer/what mechanism you are trying to improve. In the conclusions, you however say that you showed improvements for the high-resolution

area - but you didn't show that it is sufficient to implement a high-resolution nest at a targeted location to improve the overall model performance across the *entire* model domain.
So, to me the motivation of the study is not clear.
If you wanted to improve overflows, why did you exclude Denmark Strait from your nested area? That is a very important location for overflows, too!

- You introduce several acronyms (FBC, IFR, etc), but you continue using the long version afterwards. I personally prefer to avoid acronyms at all cost unless very established ones, as it improves reading flow tremendously. Either stick to using the acronyms consistently and introduce them the first time you are using the term, or simply stick to the word and don't use the acronym at all. In latex, I do recommend using the acronym package which ensures that an acronym is introduced the first time it is used and not afterwards.

- Generally, I think that the different geographic locations could be introduced more clearly as they are relevant to follow the paper. Even though I know the area very well, I was sometimes confused about the different parts of the Greenland-Scotland Ridge, as I've usually seen people discussing only one part of the ridge or the ridge as one entity. Most people also don't differentiate clearly between Faroe-Bank Channel and Faroe-Shetland Channel. You do this very well and are very accurate in using the different terms, but I suggest to introduce the Greenland-Scotland Ridge as a whole, and then separate it into the different parts, where you already point out which parts you will be talking about most. Please also make clear that you distinguish between the FBC and the FSC and calculate inflow through FSC but outflow through FBC. It makes sense to those familiar with the region, but could be stated more clearly for example as part of the method section

- You introduce the IFR as a relevant section, but you do not calculate any transport across this section, but only use it as a geographic reference. I would remove the black line marking the IFR section from Figure 1 unless you explicitely use it.

- To me it seems as if you are making an inflow-outflow budget only around the Faroes (inflow of AW through Faroe-Shetland Channel and section N, overflow outflow only for Faroe Bank Channel). We know this area quite well from observations. What additional value does the model add? At least in the outlook, you could state what kind of questions you would like to answer with this specific model. Could it be sensitivity studies?

- In the discussion you claim that "*Atlantic water crosses the IFR in a more unsteady manner with recirculations and formation of eddies. The IFR inflow branch can best be monitored at Section N, where the flow narrows along the Faroese slope*". To convince me that Atlantic Water flow across section N actually represents the entire second branch of the North Atlantic Current, I would like to see a map of the model domain showing AW volume integrated over the water column at each grid point, with the sections overlaid, which then should also be part of either the methods chapter or appendix. Also, it would be great to have this statement earlier in the manuscript. I would put it into the methods section where you should quickly reason for the sections you chose.

- This is very much personal preference, but would it be possible to shorten the Discussion chapter significantly by moving part of the discussion into the Results chapter? Currently, you repeat nearly the entire Results chapter in the Discussion part of the paper, which is slightly tiring to read. I do accept if you want to differentiate results from discussion, but I would personally prefer the Discussion chapter to contain a discussion of the *implications* of your results, while the results are already put into *context* where they are presented. That makes it a lot easier to follow why you did what you did.

- Please differentiate clearly between "model" and "setup". You refer both to the "*Nested setup*" and the "*Nested model*". If I understand correctly, both Nested and Parent are build on the same NEMO model, so they would be referred to as different setups of the same model.
- The method chapter does not contain the information necessary to fully understand what you did. I will point out what is missing in detail in the Specific Comments.

Specific Comments

l. 16/17 "*In the AMOC, cold and dense water masses flow southward in the deep ocean while warm Atlantic water from the South is transported towards the Arctic in the upper ocean.*" This is slightly misleading as it is unclear where "*the South*" is - I am immediately thinking about the Southern Ocean. I think I would swap the first two sentences of your introduction, start with a slightly zoomed-out perspective (what is the AMOC) and then say how this is important for the currents across the Iceland-Faroe-Scotland Ridge: " *As part of the AMOC (Atlantic Meriodional Overturning Circulation), warm water originating from the tropics and subtropics flows northward at the surface. At high latitudes, this water is cooled and transformed into dense water that returns southward as a deep ocean current. A significant part of this transformation happens north of the Greenland-Scotland Ridge [Lozier et al., 2019; Chafik and Rossby, 2019], which obstructs free exchange between the Nordic Seas and the subpolar North Atlantic. As such, it is important to understand flow of both warm surface water and cold transformed water across the Iceland-Faroe-Scotland Ridge. The majority of warm Atlantic Water enters the Nordic Seas between Iceland and Scotland (how many Sv or what percentage?)(Østerhus et al., 2019; Rossby et al., 2018) and also a significant portion (what percentage) of the dense water leaving the Nordic Seas as Overflow Water flows through the Faroe-Bank Channel (Olsen et al., 2008; Bringedal et al., 2018). Therefore, we focus this study on the area around the Faroe Islands.*"

l. 28 "*. that can be observed at the hydrographic section "Section N".*" There should not be a full stop here after the parenthesis. Where is "section N"? Please point to Figure 1, otherwise the reader may think he/she is expected to know where the section is.

l. 29 "*Overflow of cold, dense water takes place*"

- You have used, but not introduced the term "Overflow" earlier. Please do this in order.
- Overflow cannot really "*take place*", it is not an event but a continuous process. "*While the majority of the overflow flows through the Faroe-Bank Channel, which constitutes the deepest sill in the Greenland-Scotland Ridge, smaller amounts flow across the Wyville-Thomson Ridge and over the Iceland-Faroe Ridge*".
- You have mentioned the Faroe-Bank Channel earlier already, and you have also stated that the majority of the overflows passes through the Faroe-Bank Channel (l. 20-21). What about combining this information smoothly and also introducing the Faroe-Bank Channel as the deepest sill already when you mention it for the first time?
- You mention the Faroe-Bank Channel, the Wyville-Thomson Ridge, and the Iceland-Faroe Ridge, but you do not mention Denmark Strait as an important location for overflows despite it being way more important than e.g. the Iceland-Faroe Ridge. Please specify that this is only true of one only considers the part of the Greenland-Scotland Ridge that is east of Iceland
- Could you indicate the Wyville-Thomson Ridge on a map? I had never heard of it before.

l. 74/75 "*The model domain covers the Arctic and the North Atlantic (north of 40°N) with a resolution of 10 km*" Could you split Figure 1 into two panels where the first panel shows the entire model domain and the second panel shows what is currently shown as the "*area of interest*"? Then it would be clear what exactly you mean by "*the Arctic*", which is a very badly defined term, but usually has the Greenland-Scotland Ridge as its southern boundary and includes the Arctic Ocean as well as the Nordic Seas.

Fig. 1

- It looks as if the bathymetry in the nested and the outer domain have the same resolution. Since the grid resolution is different, I would have expected to see a difference, simply because you want to show the resolution that the model "sees". You write that the higher resolution bathymetry is just an interpolated version of the lower resolution bathymetry. Wouldn't it be better to actually have a higher resolution bathymetry for the nested domain, since you are focusing on this bathymetrically difficult region?
- I am impressed that you found two so similar colormaps for this purpose, but I think it would be better to use the same colormap for both parts of the domain to not artificially generate an impression of discontinuity at the boundary between the domains. If it is essentially the same bathymetry anyways, I don't see a reason for highlighting the changes by introducing a different color map.

l. 90 "*The hourly output frequency was required to correctly calculate the transport of water of certain temperature and salinity in highly variable flow conditions. (See also Appendix B.)*" You state what you need the hourly data for, but you don't state what you need the daily and monthly output for - although that is what you are mostly using. I would slightly restructure this part: "*Both simulations run until the end of 2020, which gives 6 years of simulations in total that are used for the analysis. The model runs with a timestep of XXX, model output is saved as monthly averages, daily averages, and as hourly averages on the sections shown in Fig. 1 (FSC, FBC, Sec. N and IFR) only. Through temporal downscaling on the sections, we show that daily data is sufficient for the analysis of transports, while transports calculated from monthly output show consistently lower transports (see Appendix B). We therefore use daily data for the analysis. The hourly output frequency was required to correctly calculate the transport of certain water masses in highly variable flow conditions.* "

l. 94 I am missing a definition of the water masses that you are using throughout the paper. Namely Atlantic Water and Overflow Water should be defined properly. You should also reason why you decide to stick to the properties that were originally derived from observations for the model. It could well be that you underestimate the transport of, e.g., Atlantic Water, because the model properties differ from the observations that they fall into slightly different T and S limits. For motivating that, you could for example show a volumetric or transport TS diagram for all sections used and overlay the boundaries that define Atlantic Water and Overflow Water, to show that you actually capture a significant part of the relevant water masses. This figure could easily be part of the Methods chapter already.
After you have defined the water masses, you can properly introduce the tracer simulations.

l. 99 "*grid cells north of the Greenland–Scotland Ridge with water colder than 2 °C and salinity higher than 34.9 psu*" Which water mass does this represent?

l. 104 You state that "*the total amount of Iceland–Scotland overflow can be calculated by spatially integrating all traced water volume south of the ridge*". What you do later on is to actually

determine the depth and location at which you find overflow water, you do not calculate a volume of total overflown water from the tracers. Could you be more explicit about what you introduce the tracers for?

l. 105 "*risks*" → "*caveats*" Could you explain what you mean by "*risk*"? Since you haven't stated yet what you want to achieve with the tracers, it is impossible to know in what way this is "risky".

l. 106 "*traced water might leave over the lateral boundaries of the parent domain*" I don't understand the problem with that, even after reading the entire paper and the appendix. You want to trace where water spreads to. Why is water then not allowed to leave the model domain? Is what you want to say with both your caveats that the water mass you are tracing gets too diluted over time, such that it becomes untracable?

l. 107 "*Resetting once a year is sufficient as will be demonstrated in Sect. 4.3*" I think the content of section 4.3 belongs right here where you introduce it. Otherwise the reader needs to jump between sections in order to understand your paper. It is also very uncommon to introduce new figures in the discussion - and I don't think it is useful to do it in this case.
Based on what you show, I am not convinced that resetting tracers every year is sufficient. You introduce a seasonal signal in overflow water transport which I assume is totally artificial. It looks as if you are calculating the concentration of overflow water south of the Greenland Scotland Ridge based on changing initial concentrations. Can you show the temporal variability at the same scale and same resolution when you calculate the transport of overflow water for the same cross-section (entire Iceland-Scotland Ridge) from just volume transports in the correct TS class opposed to the transport of overflow water calculated from tracers? If they have the same seasonality, I am convinced that the annual restoring is sufficient.

Fig. 10 Where do the spin-up periods suddenly come from? I thought you had one spin-up period of 6.5 years prior to the model runs? Why do you stop tracing after 20 months?

l. 130 "*The updated version takes into account the changes in the altimetry grid and processing.*"→ "*The updated version takes the changes in the altimetry grid and processing into account.*"

l. 131-135 "*The inflow of Atlantic water at Section N is evaluated against observed monthly averaged volume transport of Atlantic water (defined as water warmer than 4 ∘C and saltier than 35.0 psu; see details in Hansen et al. (2015)). Transport values are derived from in situ observations combined with satellite altimetry and are available from 1 January 1993. Details on the calculation method can be found in Hansen et al. (2023) and the data is available at (url)*". Can you evaluate on what kind of data it is? I assume it is ship data, but it could be X-CTDs, it could also contain Argo data, maybe even gliders. Are in-situ data only hydrographic data or do you also have ADCP data? Please just provide a quick overview for readers who are not working with this dataset every day.

l. 136-139 Same as above, please provide slightly more details about the data themselves. How was the velocity field obtained? Usually one has point measurements and interpolates between stations, but maybe you have high-resolution sections available?

Fig. 2

- Please state in the figure caption that this is showing only the nested domain of the model.
- Can you make the figure slightly wider to fill the page width?

- Can you increase the fontsize for the colorbars? Since all panels are using the same colorbar, you could consider using only one colorbar for easier understanding.

l. 163 "*on average, a transport of* 2.61 Sv *is observed*" Could you provide the standard deviation together with the mean? Then it becomes more obvious how "*considerable*"/significant the overestimate of the Parent-Only simulation is.

l. 176 "*These thresholds correspond to the definitions used in the observational data set. We refer to this warm and salty water as "Atlantic water"*." It would be much cleaner if you put the definition of Atlantic Water into the methods section. Then you wouldn't need to repeat it at the beginning of each section.

l. 191 "*where "kinematic" best corresponds to waters colder than* 6 °C" I think you need to explain this a bit more in detail. The concept of "kinematic overflow" is not very common, as overflows are usually defined in terms of density ($\sigma_0 > 27.8 \frac{\mathrm{kg}}{\mathrm{m}^3}$). I also don't follow why you use the 6 °C isotherm if you could compare to kinematic velocity directly since you have gridded velocity fields available across the section? Wouldn't it then be better to just stick to the more common density definition, particularly taking into account that 6 °C is a very high temperature for overflows as this would usually fall into the AW class? How much would Fig. 5 differ if you used the same definition of "kinematic" overflow as Hansen and Østerhus [2007]? Also, this definition of Overflow Water is different from what you use for tracers, where you defined Overflow Water as water being colder than 2 °C and saltier than 34.9 psu (e.g. l. 99 and l. 211).

l. 211 "*The tracer concentration at bottom level after 12 months of simulation*" Why would you only look at the bottom level? This assumes that Overflow Waters are the densest waters of the subpolar North Atlantic in your simulation - is that actually the case? It could also be that the overflow water takes up so much volume that it covers several vertical levels. Have you considered using the vertically integrated tracer concentration at each grid point instead of the bottom concentration only?

Fig. 6c Consider adding panels showing the weighted depth average of the overflow tracers.

l. 214 "*After 12 months, the amount of traced Overflow Water at bottom level is 100 % in the area north of the Greenland–Scotland Ridge, where tracers have been initialized*". Why only after 12 months? It should be immediately at 100 % if that is where you initialize the tracers? If they are only initialized in a certain depth layer, they should never reach the bottom level in the Nordic Seas, because the Nordic Seas have much denser water below the sill level (at least according to observations).

l.216-217 "*Overflow Water is also found over the Iceland–Faroe Ridge and south of the Wyville–Thomson Ridge, indicating that these are further overflow regions*". I am surprised that you don't see any overflow across Denmark Strait though (Fig 6). You write in the method part, that you delete tracers from Denmark Strait. This brings me back to the question about the aim of the study:

- If you, as you state, want to proof that one can improve the overall model behaviour by increasing the resolution in only a subdomain of the model, I think you are missing the point here. By selecting the region over which you increase the resolution, you select the processes that you deem to be relevant for the entire model domain. Limiting yourself to only parts of the Greenland-Scotland Ridge and missing substantial overflow through Denmark Strait is quite a choice - I may even say a caveat. Please comment in that, latest in the discussion.

- If you want to estimate the strength of overflows through Faroe-Bank Channel or where they end up, please state that explicitely.

Fig. 7b I am not entirely sure what is shown in panel b: The caption states it is "*the **absolute difference** between Nested and Parent-Only simulations in total traced water volume*" while the axis label states that it is the "*total traced water volume*". Since you obtain negative values, I assume that this is showing a difference, but not an *absolute* difference, which would always be positive. It also seems as if you are maybe showing a cumulative quantity instead of a total one?

l. 237 "*by month 18*" How do you see timing from Figure 7?

l. 269 "*This can be explained by a stronger retroflection of the Faroe Current around the north-eastern tip of the Faroe Plateau* " Not all your readers will be aware of all the small-scale features of meandering or re-circulating currents of the Faroe Current. It would be incredibly helpful to better understand your results if this information was already given where you describe the results. Then you would not need to repeat the entire paragraph here.

l. 273 "*Rosengarten Bank*" This location is not indicated on the map. Could you add it for readers less familiar with the area?

Fig. 8 Why is this Figure not part of the results section?

l. 347 "*Comparing "new" and "old" simulations*" What do you mean by new and old? Like simulations from the beginning and end of the period? Or did you run these simulations several times? Or do you mean comparing two simulations where the tracer was released in consecutive years? I thought you are using one spun-up simulation that runs for 6 years and you only release new tracers once a year? Why are you suddenly having so many spin-up periods and individual simulations here?

l. 349 "*found no signs of traced water leaving the parent model domain*" I still don't understand why this is important or an argument that underpins the sufficiency of annual tracer releases.

Minor Comments

l. 5 "*A dye passive tracer is used to clarify the course of cold overflow water masses.*" The word "*clarify*" does not make sense in this context. Maybe use "*illustrate / demonstrate*"

l. 11 "*decent*" → "*descend*"

l. 14 "*large scale water transports*" → "*large-scale water transports*" (compound modifier)

l. 27 "*the Atlantic water turns southeastward following the slope where it confines to the Faroe Current*" Maybe rather "*narrows*" instead of "*confines*"?

l. 45 "*This approach is, however, computationally extremely demanding*" → "*costly*" rather than demanding.

l. 55 "*cheaper nest*" → "*computationally cheaper nest*"

l. 76 "*In this "Nested" setup*" Why do you put "*Nested*" in quotes and why do you capitalize it? It is a valid expression, isn't it?

l. 120 "*From the simulated daily sea surface height (zos) [...] (ssh_ib)*" I would leave out the variable names that were used in the model. You don't use them anywhere else in the manuscript.

l.158 "*utilize*" → "*use*" (utilize has a connotation of to use something in a non-intended way, so it rather means to abuse than to use)

l. 184 "*small seasonal cycle*" → "*weak seasonal cycle*"

l. 186 "*depicted as semi-transparent shadings*" → "*depicted as semi-transparent shadings in Fig. 4b*"

l. 194 "*as solid lines*" → "*as solid, coloured lines*"

l. 200/201 "*are simulated very well*" → "*However, maximum and minimum values in July and February, agree well between the Nested simulation and the observations.*"

l. 239 "*clarifies*" → "*emphasizes*" or "*confirms*"

l. 257 "*can resolve*" → "*resolves*"

l.258 "*no conclusions are possible*" → "*no conclusions can be drawn*"

l. 257 "*but the average flow pattern is robust*" → "*but the average flow pattern is robust over the model period in both simulations.*"

l. 265 "*both the Parent-Only and the Nested simulation show a relatively too low sea level compared to the altimeter observations*" → "*both the Parent-Only and the Nested simulation show a lower sea level than the altimeter observations*"

l. 273 "*A region of high sea level usually present over the Rosengarten Bank, indicating some recirculation.*" This is not a sentence. You could fix that by adding a *to be* if that is what you want to convey: "*A region of high sea level **is** usually present over the Rosengarten Bank, indicating some recirculation.*"

l. 294 "*before (= south of)*" → "*upstream of*"

l. 324 "*This supports our approach*" → "*justifies*"

l. 328-330 "*Better suited for cases like overflows, where isopycnals follow a slope, are for example isopycnal coordinate systems (Wang et al., 2015) or types of terrain-following coordinate systems (Bruciaferri et al., 2024).*" Sentence order sounds somewhat odd to me. What about: "*For cases like overflows, where isopycnals follow a bathymetric slope, isopycnal coordinate systems (Wang et al., 2015) or types of terrain-following coordinate systems (Bruciaferri et al., 2024) are better suited.*"

l.335 and elsewhere "*fate of the overflow waters*" fate is a very spiritually connoted word. In this case, you could use "*pathways*".

l. 351 "*juxtaposing*" would it be sufficient to use the more common word "*comparing*"?

l. 383 "*deeply sinking overflow waters*" → "*deep-sinking overflow waters*"

l.388-389 "*Whereas*" either replace with "*while*", or turn sentence around:
"*While the average current speed barely reaches 0.3 m s-1 in the Parent-Only simulation, there is a flow of 0.4 m s-1 with the nest.*" OR
"*There is a flow of 0.4 m s-1 with the nest, whereas the average current speed barely reaches 0.3 m s-1 in the Parent-Only simulation.*"

l. 403 "*like presented in*" → "*as presented in*"

l. 404 "*even in its current setup the Nested model*" → "*even in its current setup, the Nested model*"

l. 406 "*over the ridge*" → "*across the Greenland-Scotland Ridge/Iceland-Faroe Ridge*"

l. 413 "*Also an improvement simulation*" → "*Further, an improvement simulation*"

References

Chafik, L. and T. Rossby (2019). "Volume, Heat, and Freshwater Divergences in the Subpolar North Atlantic Suggest the Nordic Seas as Key to the State of the Meridional Overturning Circulation". In: *Geophysical Research Letters* 46.9, pp. 4799–4808. DOI: \url{10.1029/2019GL082110}.

Hansen, B. and S. Østerhus (2007). "Faroe Bank Channel overflow 1995–2005". In: *Progress in Oceanography* 75.4, pp. 817–856. DOI: 10.1016/j.pocean.2007.09.004.

Lozier, S. M. et al. (2019). "A sea change in our view of overturning in the subpolar North Atlantic". In: *Science* 363, pp. 516–521. DOI: \url{10.7924/r4z60gf0f}.